RELATIONS AMONG BONE HEALTH MEASURES AND BEVERAGE INTAKES DURING THE BONE BUILDING YEARS

A Thesis

Presented in Partial Fulfillment of the Requirements for

Graduation with Distinction from the School of Allied

Medical Professions of The Ohio State University

By

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The Ohio State University
2011

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Background

Osteoporosis is a complex, multifactorial disease. The health of the human skeletal system is under the influence of numerous contributing factors, both modifiable and not, which are constantly affecting the formation and/or breakdown of bone (1). Milk may be seen as the emblem of bone health and the drink of choice in regard to bone building (2). However, the effects of a wealth of other beverages on bone health, osteoporosis and fracture risk are often underestimated. A better understanding of such effects coupled with primary prevention methods may promote the use of dietary approaches to decrease the prevalence of osteoporosis. According to data from NHANES 2005-2006, there has been a recent decline in the number of adults affected by osteoporosis. In 1988-1994, NHANES found 7.3 million adults had osteoporosis of the femur neck, with a drop to 5.3 million in the 2005-2006 study. However the disease is still prevalent, in addition to the 5.3 million adults with osteoporosis at the femur neck, 34.5 million had osteopenia, often a precursor to osteoporosis (3).

Due to the asymptomatic nature of the disease and a lack of physical signs, it has been coined the "silent disease" (4). In addition, the likelihood of osteoporosis developing is affected drastically by actions, including dietary choices, of children and young adults, hence the title "pediatric disease with geriatric outcomes" (5,6). At an age so crucial to the development of optimal bone health, beverages like soda and juice are at their peak of popularity (7). The harmful effects such choices have on bone are not instant nor are they immediately felt, but often emerge later in life in the form of fractures. Fractures of the femoral neck, wrist, vertebrae, and hip are generally those which occur in severe osteoporosis (8). The costs associated with the disease are vast,

including hospitalization, surgery, medications, loss of work time, and the like. As the rate of osteoporosis remains high, the economic burden on the health care system and the country will as well (9).

Related Research

Adolescents are in the midst of an influential period of life referred to as the bone building years. During adolescence and puberty, the skeletal system is undergoing a rapid period of growth and change resulting in a substantial portion of bone building occurring within this time frame. Wang et al. (10) studied pubertal girls ages 10-13 and found that adolescent girls undergo a period of decreased bone mineral density (BMD) and increased fracture risk prior to menarche, but during and shortly after menarche experience a rapid increase in BMD within the tibial shaft. This period of change requires a consistent and plentiful influx of calcium, and various influential factors can prevent, hinder, or assist in the success of this physiological process.

It is critical to remember that bone is living tissue, and just as other living tissues change with age, bone does as well. Bones continue to grow and change shape as well as composition beyond adolescence in response to levels of calcium, vitamin D, and other substances within the body, and in response to inevitable bodily processes associated with aging. It is a common misconception that calcium is used solely for this process, where in actuality it is used by the entire body to support major physiological functioning. The human body requires a constant level of calcium to be circulating within the blood, and when calcium is consumed in excess, what is not needed is stored in the bone via the activity of cells known as osteoblasts, and the body maintains an appropriate balance. If an inadequate amount of calcium is circulating, the blood will

pull calcium from the bones through the action of cells known as osteoclasts; thus the body maintains an appropriate balance. The human skeletal system works constantly to balance bone formation with bone resorption, a process known as bone remodeling. If excessive amounts of calcium are pulled from the bone without a counteracting deposition of entering calcium, it can lead to changes in bone shape and structure, and the formation of pore-like crevices throughout (11). The porous appearance of the affected bone gives the condition its name, osteoporosis (1). It is well understood that this process of bone remodeling evolves into a significant issue within the elderly population as a result of decreased calcium and vitamin D intake, decreased calcium absorption secondary to vitamin D deficiency, and lack of sun exposure due to institutionalized care. Brazier et al. (12) found that elderly men and women with known vitamin D deficiencies presented with significantly higher levels of bone remodeling indices, which were decreased following the administration of vitamin D supplementation.

Several dietary factors, including vitamin D status, have been linked to development of optimal bone health or osteoporosis. Vitamin D, either from food sources or from exposure to sun light, has been shown to be essential in the intestinal absorption of calcium and thus the maintenance of bone mineral content (BMC) and BMD (13,14). Considering that 99% of the body's calcium is found within mineralized tissue, including bone, logic suggests that calcium from both food and supplements is a primary factor in the maintenance of optimal bone health (1). Johnston et al. (15) supported this concept by finding that prepubertal adolescents who consumed calcium at or above the recommended levels had a subsequent increase in BMD later in life.

Phosphorus is an element which is intertwined into bone homeostasis and calcium metabolism with a sensitive balance. Phosphorus is necessary in maintaining adequate levels of calcium within the body, but when consumed in excess can actually have the opposite effect by increasing bone resorption and the overall loss of calcium present for the mineralization of bone demonstrating that a high phosphorus diet is capable of lowering bone mass. Recent research has taken into consideration the hypothesis that a major source of phosphorus in the diet of many Americans is dark sodas, or colas, which contain phosphoric acid. The average cola can have as much as 19.7 mg/dL of phosphorus (18). Though phosphorus is required by the human body, the excessive consumption of dark sodas can lead to an intake that exceeds the RDI of 1750 mg/day for adults or 700 mg/day for children (19). Therefore it has been suggested that an increase consumption of cola has lead to excessive intakes of phosphorus, and a subsequent increase in bone loss.

Vitamin D, calcium, and phosphorus are traditionally known as the bone nutrients, and these work synergistically to greatly impact bone health. However, there has been some suggestion that other nutrients, including fat, sodium and protein, can also have an impact. Hsu et al. (20) found a significant, negative relationship between bone mineral concentration and cholesterol, triacylglycerol, and LDL concentrations, proposing that excessive dietary fat within the body may inhibit the actions of osteoblasts. Sodium intake may also lead to increased calcium excretion and therefore increased rates of bone resorption and lower BMD (21, 22). Mizushima et al. (23) studied Japanese women and found those who received a larger portion of their calcium from the bones of salty fish had lower BMD. A proper intake of protein is also necessary

for bone health. In a meta-analysis conducted by Darling et al. (24), it was concluded that a positive correlation exists between total protein intake and increased BMC/BMD for nearly all bone sites. Additionally, approximately 1-2% of total BMD could be attributed to dietary protein intake. It is worth noting that milk can serve as a major protein source in the diet, therefore a decrease in milk consumption can lead to a decrease in calcium, vitamin D, and protein intake.

The addition of regular physical activity, specifically weight bearing exercise, has been shown to assist in the attainment of optimal bone health. Gunter et al. (25) conducted a study in which children underwent a seven-month intense jumping program. When compared to control eight years later, the children who underwent the jumping program had a significantly higher hip BMC. Similarly, a higher body mass index (BMI), preferably due to increased lean muscle mass, has also been shown to increase bone strength (26,20).

A large determinant of bone health also lies within a person's genetic code. Numerous twin studies have supported the hypothesis that a majority of a person's bone health is genetically determined: up to 80% (25, 27, 28). Another non-modifiable risk factor for osteoporosis is gender: men and women face drastically different influences on bone health. At a young age, women have smaller bones and higher BMD than men (29). Both men and women experience a decline in bone strength and BMD with age, though women face a more rapid decrease as a result of menopause and subsequent loss of estrogen and therefore often develop a lower BMD than their male peers (30). This loss of estrogen combined with smaller bones can put women at a higher risk for bone loss, osteoporosis and fractures. Race is an additional determinant of bone health. Yin et

al. (31) found that male and female Chinese and African Americans had similar rates of calcium absorption that were higher than that of their Caucasian peers. This coupled with the finding that African Americans also display less calcium excretion leads to higher calcium retention and greater peak bone mass for those individuals.

Regardless of these non-modifiable risk factors, there is a lot to be said with respect to the control of harmful dietary influences and promotion of those that are beneficial. Taking into consideration the ramifications of harmful dietary practices during adolescence, addressing current practices of U.S. teenagers is worthwhile. As previously noted, milk tends to be the symbolic link between diet and bone health, however the dominant beverage of choice for adolescents seems to be sugar-sweetened beverages (SSBs: soda, sport drinks, fruit drinks and punches, low calorie drinks, sweetened tea, and other sweetened beverages). Wang et al. (7) analyzed the dietary recalls of adolescents from NHANES and found that between 1999 and 2004, 84% of adolescents drank SSBs at an average rate of 20 ounces a day. 20 ounces of SSBs is equivalent to approximately 356 kcal, 16% of their daily energy intake. In addition, two-thirds of the SSBs consumed by adolescents were carbonated sodas. A focus on the consumption of SSBs in the form of 100% fruit juice may seem optimistic due to its equivalence to whole fruit, however it has been shown that many children consume more than their recommended amounts. This poses a problem in that there is a strong chance adolescents are replacing what would otherwise have been milk with SSBs (100% juice or any other form), therefore calcium requirements are not being met. An additional problem is that this may not be a short-term trend, potentially remaining somewhat constant through later years of life. Also using NHANES, Bleich et al. (32) found that

between 1999-2004 63% of adults consumed SSBs. Although bone building in adulthood is not occurring at a comparable rate to that of adolescents, a decrease in dairy consumption can lead to decreases in circulating calcium and therefore bone loss. This concept is supported by the fact that the per capita demand for milk has declined steadily since 1990, from just above 55 quarterly pounds per year to approximately 46 in 2005 (33).

If adults are drinking more soda, they are likely drinking less milk (34). However, a second danger of soda comes from the harmful effects of the phosphoric acid. Tucker et al. (34) obtained data from participants in the Framingham Osteoporosis Study through the Framingham Osteoporosis Cohort to assess the correlation between BMD and carbonated soda consumption. All subjects provided informed consent, and the final analysis consisted of 1125 men and 1413 women. BMD was measured using dual X-ray absorptiometry (DEXA) at the right hip (total hip, trochanter, Ward's area, and femoral neck) and the lumbar spine (L2-L4). When the participants were controlled for confounding factors, including calcium intake, a consistent pattern was seen between cola consumption and low BMD. Non-cola sodas (i.e. those without phosphoric acid) also appeared to have an affect on BMD, but instead due to the effects of caffeine. Of the carbonated beverages consumed by the study participants, >70% were colas containing phosphoric acid and one-half of those consumed by women and three-fourths of those consume by men contained caffeine. Their research found that there was a significant correlation between increased cola consumption and decreased BMD in women: women who drank zero beverages had an average femoral neck BMD of 0.89 g/cm^2. The

femoral neck BMD of women decreased consistently as more colas were consumed, with women consuming >7 having 0.855 g/cm^2.

Guerrero-Romero et al. (18) tested the same hypothesis through a case control study of postmenopausal women. The cases were defined as women with a serum calcium level $\leq$ 8.8 mg/dl and controls as a level >8.8. All were women with at least six months of menopausal duration. Home visits and interviews were conducted to determine the amounts of cola beverages consumed over the past year and therefore phosphoric acid consumption. Serum levels of calcium, phosphrorus, and albumin were measured with a clinical chemistry automatic analyzer (Ciba Corning Diagnostic Corp, Overling, OH). Serum calcium levels for the case and controls were found to be 7.8 $\pm$ 0.6 g/dL and 9.1 $\pm$ 0.4 g/dL, respectively (a normal serum calcium level is 8.8–10.7 mg/dl). Of the 21 women with serum calcium levels $\leq$ 8.8 mg/dl, ten, or 47.6%, drank one or more bottles (375 mL each) of phosphoric acid-containing soda per day. Using regression analysis, it was found that phosphoric acid containing sodas had a strong and independent association with hypocalcemia (P=0.005) for women who drank one or more bottles a day. Women who consumed these beverages also exhibited increased PTH levels and unaffected (normal) 1,25-dihydroxyvitamin D levels, indicating a suppressed response to increased PTH, which under normal conditions would lead to an increased intestinal calcium absorption, resulting in hypocalcemia and eventual bone resorption.

Studies conducted have also found an association between phosphoric acid in carbonated beverages and the bone health of young adolescents. Wyshak et al. (35) conducted a cross-sectional study of four hundred ninth and tenth grade girls with a mean age of fifteen years, to whom he administered questionnaires to determine physical

activity and carbonated beverage consumption. He assessed the girls' carbonated beverage consumption and bone health, in the form of fracture occurrence. Of the girls, 80% drank carbonated beverages, 49.8% drank cola beverages only, 11.5% drank non-cola beverages only, and 15% drank both. Therefore, 460 of the girls consumed cola beverages. The results showed one fifth of the girls had a history of bone fractures. For all girls, the odds ratio (OR) for the association of bone fractures and drinking carbonated beverages was 3.14, P = .004, and for the girls with the highest reported physical activity, the OR was 7.00, P = .002. The relationship between phosphoric acid and hypocalcemia has also been investigated. Mazariegas-Ramos et al. (36) conducted a case-control study of children from primary care facilities of the Mexican Institute of Social Security and from elementary schools belonging to the government educational system in Durango. Cases were defined as children with a serum calcium level < 2.2 mmol/L (8.8 mg/dl), and controls as children with $\geq$ 2.2 mmol/L. The study included 57 cases and 171 controls from which 3 mL blood samples were taken to determine levels of calcium, phosphorus, and albumin using a clinical chemistry automatic analyzer (Ciba Corning Diagnostic Corp., Overling, Ohio) with colorimetric techniques. The children were also interviewed with their mothers present, to determine how many cola beverages they consumed. Of the 57 children within the case group, 38 of them (66.7%), consumed more than four bottles of soda a week, while only 48 (28%) of the children within the control group consumed greater than four (OR = 5.27%, P = < 0.001). For all of the children in the study, a significant negative correlation was found between serum calcium levels and the amount of soda beverages consumed per week (P = < 0.001). It was also found that of the seventeen children that participated in a follow up, basal serum calcium levels rose

from 8.7 ± 1.0 mg/dL to 9.4 ± 0.6 mg/dl (P = < 0.003) and serum phosphorus levels dropped from 5.7 ± 1.3 mg/dl to 4.7 ±0.6 mg/dl (P = <0.002) thirty days after soda consumption was discontinued. Despite these studies, this hypothesis requires further research, due to the lack of statistically significant results found by other researchers, including Kim et al. (37) who found no significant relationship between carbonated beverage consumption and BMD.

The study by Tucker et al. (34) mentioned above also considered the potentially harmful effects of caffeine on bone health. The research that has tested this hypothesis is relatively inconsistent. There has been some evidence to show that caffeine increases the rate of calcium excretion in general (38, 39) however there seems to be more consistent findings that caffeine/coffee consumption poses a higher risk in adult populations. Hernandez-Avila et al. (40) sent questionnaires to the participants of the Nurses' Health Study to determine caffeine intake along with follow-up questionnaires to assess the occurrence of fractures. Of the participants, it was found that 75% were coffee drinkers and 44.7% were tea drinkers. It was also found that the women who consumed 192-359.9 mg/day had an age-adjusted risk of fractures that was 2.38 and women who consumed $\geq$ 817 mg/day had a risk of 2.96. The study concluded that there is a significant increased risk of hip fractures as coffee consumption increases (P = .004).

Hallstrom et al. (41) conducted a study of 1,016 elderly men and women above the age of 70. The caffeine consumption of 850 of the participants was assessed through the use of a seven-consecutive day diet diary, with special attention paid to coffee and tea. BMD was also measured using DEXA scans of the total proximal femur, femoral neck and trochanteric regions of the proximal femur. Nearly half of the participants

reported consuming three to four cups a day, with one fourth reporting more than four cups. After comparing BMD to total cups of coffee, there was a significant, negative relationship between amount of coffee consumed and BMD (P = .04). In addition, men who consumed four or more cups a day had 4% lower BMD of the total proximal femur than men who drank 0-2 cups a day (P = .04). BMD of the femoral neck and trochanteric region of the proximal femur was 3-5% lower in men who consumed four or more cups a day (P = .05 and .01, respectively).

Beverage consumption cannot be discussed without reference to milk's effect on bone health. Soroko et al. (2) analyzed data from 581 women who participated in a heart disease survey in Rancho Bernardo, California. These 581 women were administered questionnaires to assess their milk intake, and received bone density scans of the lumbar spine and hip using DEXA. All women were Caucasian and had an average age of 70.6 years. It was found that there was an independent, significant relationship between increased milk consumption and higher BMD within the midradius, spine, total hip, intertrochanter, and trochanter. In addition, higher reported milk consumption as a teenager was associated with a significantly higher BMD at the spine and midradius.

Kalkwarf et al. (42) found similar results in their study of adolescent milk intake and consequential adult BMD. Using data from NHANES III, the BMD of the left hip of 3251 women (right on those who had previously fractured the left) scanned using DEXA was analyzed and compared to data regarding milk intake acquired through home dietary interviews. From the study, it was found that women who reported consuming less than one serving of milk a week had a 2-3% lower BMD of the hip than women who reported consuming more than one serving of milk a day in childhood and adolescence.

Furthermore, in women ≥ 50 years old, those who reported a low milk intake during childhood had double the fracture risk than women who reported a high intake.

Based on the research presented, it is evident that excessive consumption of any beverage, be it soda, juice or other SSBs, paired with lower milk consumption has a harmful affect on bone health. Kristensen et al. (43) assessed the bone health of young men based on soda consumption, not by assessing intakes of phosphoric acid, but instead by assessing a subsequent lack of milk consumption. The cross-over study recruited eleven Caucasian males aged 22-29, who were directed to follow a low-calcium diet combined with either 2.5 L of Coca Cola or milk, and mineral water ad lib. The diet period with each beverage lasted ten days, with a wash-out period in-between. The calcium and phosphorus content of the meal was analyzed and found to be 3,500 mg/day and 3,640 mg/day, respectively when milk was the main beverage, and 470 mg and 1,690 mg, respectively, when Coca Cola was the main beverage. The Coca Cola alone was reported to provide 425 mg of phosphorus. Overall, it was found that when the men were placed on the Coca Cola containing diet, there was a significant increase in calcitrophic hormones and biochemical markers of bone turnover, compared to levels consistent with the milk containing diet.

An additional beverage that appears to have an effect on the bone health of adults is alcohol. In the study conducted by Hernandez-Avila et al.(40) mentioned previously, an increased risk of hip fracture was found for women who reported a moderate intake of alcohol (5-24 grams a day). When adjusted for age, the risk for women who drank no alcohol compared to those who drank ≥ 25 grams a day was 2.35. After adjusting for possibly confounding variables (including caffeine consumption), the risk lowered

significantly, to 2.33. A cross-sectional study of 57 noncirrhotic alcoholics (37 male, 20 female) between 27 to 50 years of age conducted by Malik et al. (44) explored the relationship between alcohol consumption and BMD. Participants chosen were considered alcohol dependent according to ICD 10 and their BMD was measured at the lumbar spine (L1–L4) and proximal right femur (femoral neck and total hip) using DEXA. The results supported the hypothesis that increased alcohol consumption lowers BMD, however the results were more significant in men. Of the men studied, nine of them, or 24.3% had a low BMD, defined as a Z-score $\leq$ -2.0. Only one woman met these same criteria; however all of the women had elevated levels of estradiol, indicating a potential protective factor and reasoning for normal BMD levels. This suggests that alcoholism at a later age my have a more detrimental effect to both men and women, due to a loss of estrogen after menopause in the latter. It is worth noting that 75.7% of men and 90% of women presented with plasma levels of 25-hydroxy-vitamin D < 30 ng/ml, indicative of an increased risk of calcium deficiency and bone loss.

Methodology

The current research data regarding various beverages – soda, coffee, tea, alcohol – and their impact on bone health is quite inconsistent. Therefore, the purpose of this study was to help reach a more concrete conclusion as to the relationship between beverage choice and bone health. The information obtained may provide the potential for evidence-based practice in the future and to help decrease the rates of osteoporosis.

Research Questions:

- What is the relationship between beverage consumption and bone health in young adults?

- Does a difference in BMC/BMD exist between individuals who did consume each beverage and those who did not?
- What is the unique contribution of the consumption of various beverages on bone health?

Sample Data

To observe the relationship between beverage consumption and bone health/rates of osteoporosis, data from The National Health and Nutrition Examination Survey (NHANES) from 1999-2004 were analyzed. We collected diet and bone health data on individuals between the ages of 20-35 years old, excluding pregnant and lactating women. Information on diet history came from 24 hour recalls and individual food files as well as total nutrient intake. From the diet recall data, eight digit food codes from the FNDDS that coincide with specific foods were used to assess beverage intakes. Bone health information was derived from data acquired from DEXA scans, consisting of total BMC (g) and BMD (g/cm^2), as well measurements of the hip/pelvis.

NHANES Overview

NHANES is a program of the National Center for Health Statistics (NCHS), part of the Centers for Disease Control and Prevention (CDC). The NHANES program originated in the 1960s, and has since developed the responsibility of acquiring health statistics and rates of chronic disease representative of the U.S. population. A series of interviews, surveys, and examinations were conducted to develop relevant data. Interviews consist of demographic, socioeconomic, dietary, and health-related questions; surveys focus on health and nutrition measurements; and examinations focus on medical, dental, and physiological measurements as well as the administration of various

laboratory tests. The surveys are especially important in assessing the risk factors for chronic diseases, including osteoporosis. To ensure that the data is an accurate representation of the population, NHANES over-samples minority populations, including African Americans, Hispanics, and adults 60 years or older (45).

Data Collection

Public use files were downloaded from the NHANES website and used for further analysis. The sample selected for analysis includes selected participants who had completed 24-hour recalls and DEXA scans.

24-hour Recall Interview

The in-person, 24-hour recalls were conducted to acquire information regarding food and beverage consumption 24 hours prior to the interview period. The information collected was analyzed to assess individual foods consumed, including the type and amount. Total nutrient intake was also assessed from both food and beverages including total energy intake, nutrients consumed, and water consumed. The in-person portions of the diet history interviews were conducted in a private room within the NHANES mobile examination center (MEC). Interviewers underwent training and supervised practice to assure the acquisition of high quality information. In 2001, the addition of the NHANES computer-assisted dietary interview system (CADI) was made to provide instructions for the interviewers for recording diet information. Measuring devices (cups, spoons, etc) were provided during the interview to ensure accuracy, and the Automated Multiple Pass Approach was utilized in a separate portion of the diet recall, a computer based, 5-step interview process to assure accuracy and efficiency. All dietary intake gathered were processed using the USDA's Nutrient Database for Dietary Studies, 2.0 (FNDDS 2.0).

Nutrient values used for the processes and coding of the dietary data is based on values in the USDA's National Nutrient Database for Standard Reference (46).

DEXA

Dual-energy x-ray absorptiometry (DEXA) scans were administered using a Hologic QDR-4500A fan-beam densitometer and Hologic software version 8.26:a3 in the NHANES mobile examination center (MEC) to eligible participants, eight years and older. Participants were scanned lying in a supine position with an X-ray source using fan-beam scan geometry in three passes. Examinations were administered by certified radiology technologists. Scans consisted of both bone and soft tissue of the total body, and for scans of both arms and both legs, the trunk, and head were provided, as well as scans of bone within the pelvis, left and right ribs, thoracic spine, and lumbar spine. Values acquired from the total body and other regions include:

- Total mass (gm)
- Bone mineral content (BMC) (gm)
- Bone area (cm^2)
- Bone mineral density (BMD) (gm/cm^2)
- Fat mass (gm)
- Lean mass excluding BMC (gm)
- Lean mass including BMC (gm)
- Percent body fat (%)

The data collected were reviewed and analyzed by the University of California, San Francisco using Hologic Discovery software version 12.0, upholding to standard

radiologic techniques and protocols developed specifically for NHANES. The information collected was then used to produce DXX data files for each participant (47).

Data Preparation

After the acquisition of diet history data, the individual food lists were analyzed and all beverages were recoded into the six categories for analysis:

- Coffee/tea
- Milk
- Soda/SSBs
- Fruit or vegetable juice
- Water
- Alcohol

Milk alone was considered a beverage in this process if not part of a combination food item (i.e milk on cereal). Total milk consumption was ultimately assessed as:

Total milk = $milk_{beverage} + milk_{other}$

The quantities of each beverage consumed by each individual was then be summed up in grams, and individuals were classified as drinkers (>0 g) or nondrinkers (0g).

Data Analysis

The data were analyzed to determine the relationship between beverage consumption and bone health in young adults. This was done using a Pearson correlation of grams of intake of each beverage category to BMD and BMC. T-tests were used to determine if differences were present in the BMC and BMD for groups who did or did not consume each beverage. From this the mean differences in BMC and BMD by

drinkers versus nondrinkers for each beverage category was assessed. A linear regression was computed to predict BMC/BMD from grams of each beverage consumed.

All data were prepared and recoded using SPSS/PASW 18.0 and data analyses was conducted using SPSS/PASW Complex Samples (version 18.0) in order to produce a nationally representative sample. The software used did so by correcting for oversampling of underserved population while providing appropriate standard deviations for statistical testing.

Results

Correlation of grams of intake to BMD/BMC

To identify the relationship between intakes of various beverages and bone health, the data were analyzed to assess the correlations of grams of intake of all seven beverage categories to both BMD and BMC, as shown in Table 1. Weak to moderate significant correlations were found between BMC and coffee and tea (P=0.011), milk (P=0.000), SSB (P=0.003), juice (P=0.002), and alcohol (P=0.000). Significant correlations were also found between BMD and milk (P=0.010), SSB (P=0.042), juice (P=0.006), and alcohol (P=0.002). There was no significant relationship between water and BMC or BMD. These findings suggest that the consumption of coffee and tea or SSB may have an effect on BMC, while the consumption of milk, juice, or alcohol may have an effect on both BMC and BMD. Our findings also suggest that drinking water has no effect on one's bone health, neither BMC or BMD.

Beverage category	Bone Mineral Content (g)		Bone Mineral Density (g/cm^2)	
	R	**P**	**R**	**P**
Coffee and Tea (g)	**0.145**	**0.011**	0.089	0.115
Milk (g)	**0.195**	**0.000**	**0.134**	**0.010**
Sugar-Sweetened Beverages (g)	**0.114**	**0.003**	**0.063**	**0.042**
Juice (g)	**0.241**	**0.002**	**0.200**	**0.006**
Water (g)	0.130	0.103	0.105	0.195
Alcohol (g)	**0.200**	**0.000**	**0.155**	**0.002**
Other (g)	0.045	0.683	-0.063	0.607

Table 1: Correlations of grams of intake to BMC and BMD

Drinkers versus Non-Drinkers

When comparing the mean BMC across consumption categories, those who drank SSBs had significantly lower mean BMC than non-drinkers (P=0.001), while those who drank water had significantly higher mean BMC (P<0.001) and BMD (P=0.038). There were no significant differences in BMC or BMD for those who drank coffee and tea, milk, juice or alcohol for BMC or BMD. These findings are further outlined in Table 2.

Prediction of BMC and BMD

To identify which beverages could be used to predict bone health, we found that with each gram of SSB (P=0.028) or alcohol (0.133) consumed, we were able to predict a significant 1 g increase in BMC (Table 3). None of the other beverages, including coffee and tea, milk, juice, or water were significant predictors of BMC. No beverage category lead to a significant prediction of BMD.

Beverage category	Consumption	Bone Mineral Content			Bone Mineral Density		
		Mean	**SE**	**P**	**Mean**	**SE**	**P**
coffee & tea	non-drinker	2469	47	0.768	1.16	0.02	0.936
	drinker	2490	41		1.16	0.01	
Milk	non-drinker	2551	65	0.117	1.16	0.02	0.822
	drinker	2431	24		1.16	0.01	
SSB	non-drinker	**2614**	**49**	**0.001**	1.18	0.02	0.094
	drinker	**2381**	**24**		1.14	0.01	
Juice	non-drinker	2484	27	0.714	1.16	0.01	0.971
	drinker	2456	78		1.16	0.02	
Water	non-drinker	**2456**	**31**	**<0.001**	**1.15**	**0.01**	**0.038**
	drinker	**2657**	**39**		**1.20**	**0.01**	
Alcohol	non-drinker	2477	38	0.971	1.17	0.01	0.315
	drinker	2480	54		1.14	0.02	

Table 2:Mean BMC and BMD of drinkers vs. non-drinkers

Beverage category intakes (g)	Bone Mineral Content		Bone Mineral Density	
	Beta	**P**	**Beta**	**P**
Coffee and Tea	0.090	0.313	0.000003	0.917
Milk	-0.182	0.193	-0.000017	0.783
Sugar-Sweetened Beverages	**-0.166**	**0.028**	-0.000023	0.412
Juice	0.067	0.730	0.000038	0.445
Water	0.176	0.082	0.000043	0.258
Alcohol	**0.133**	**0.007**	0.000025	0.140

Table 3 Prediction of BMC and BMD based on grams of intake of each beverage category

Discussion

In this study, we hypothesized that the beverages included in our analysis could be separated into three broad categories based on their possible effects on bone health. This included those with a protective effect on bone, including milk; those which may displace the consumption of milk, including juice; and those with potentially negative

physiological effects, including certain SSBs. We based these assumptions on current research, some of which suggests that coffee and tea as well as SSBs (specifically dark sodas) may have negative physiological effects on bone.

Unlike what we expected, coffee and tea were associated with an increase in BMC, however there was no difference in the mean BMD of those who drank coffee and tea and those who did not. These findings do not entirely agree with those of the research presented, which suggest that caffeine increases calcium excretion and that coffee drinkers have both lower BMD and an increased fracture risk (38, 39, 40, 41).

Like that of coffee, the popularity of juice has escalated in recent years. It is important to consider that juice may be replacing what would have otherwise been milk, leading to a subsequent decrease in consumption of milk and ultimately having a negative consequence on bone health. Our research shows that juice consumption was related to an increase in both BMC and BMD, which is not consistent with the results we anticipated. However, the non-drinker of juice did have a higher BMC, although this finding was not significant. Though it is difficult to prove exactly what is to blame here, the research does support our original proposed theory (43).

Current research suggests that dark carbonated sodas are responsible for bone resorption and other negative effects on the skeletal system (34, 18, 35, 36). In our study**,** we found that the consumption of SSBs was associated with an increase in both BMC and BMD, but SSBs were also associated with a decrease in BMC, and drinkers of this beverage category had a significantly lower BMC. However, we did not assess the unique effects of only dark carbonated sodas, so we cannot conclude that these findings

are the result of this type of beverage alone. Similar patterns of milk displacement may occur with SSBs as well, further increasing their negative effects.

In addition to SSBs and juice, we assessed the data for evidence of a protective effect of milk on bone health. It was indeed positively related to BMC and BMD, and therefore does appear to have a protective effect. However there were no significant differences in BMC and BMD between drinkers and non-drinkers, which suggest that contrary to popular belief, it may not be as protective as once though. An interesting finding was that, although statistically insignificant, milk drinkers actually had a lower BMC and BMD, which most would consider rather counterintuitive. This finding supports the evidence that an individual's bone health is in fact a culmination of numerous factors, one of which may include beverage consumption, but that this factor is not acting alone. Given milk's high calcium content, one may believe that drinking milk is a guarantee of optimal bone health, however it appears as though this is not exactly the case. Milk (i.e. calcium) intake in addition to factors such as gender, genetics, physical activity level, weight, medication regimen, amongst many others, all work together to establish one's bone density and health.

We also found a couple of unanticipated results, one being that water was related to higher BMC and BMD, and that water drinkers had a significantly higher BMD and BMC. This suggests that water may have a protective effect on bone, however another possible theory is that individuals who drink water may live healthier lifestyles altogether, and may consume calcium rich foods and beverages as well as take part in an overall healthy lifestyle that further helps to build and protect bone, such as exercising. Similarly, we found that alcoholic beverages are associated with a higher BMC and

BMD. Lastly, those who reported drinking alcohol did have a lower BMD, however this finding was short of being significant.

Although the results we found did not exactly fit into what we had expected, our findings do support the common concept in nutrition that everything is okay in moderation. What we had expected to find was that individuals who consume SSBs, juice, coffee, and tea would have lower BMC and BMD, which for the most part was not exactly the case. When reviewing our findings, it is important to keep in mind that the data we analyzed were from one snapshot in time, one twenty-four hour period. If someone drinks a Diet Coke, for example, or a glass of orange juice, these choices are not detrimental to their bone health. Similarly, one glass of milk, or putting milk on one's cereal, is not a promise of optimal bone health. Instead, it is important to look at habitual consumption. Someone who constantly chooses juice or soda over milk is likely to see negative effects on their bone health, just as those who strive to consume their recommended levels of milk everyday are apt to maintain their optimal bone health.

In our study, we chose not to control for such factors as race, gender, activity levels, or weight in hopes of observing the effects of beverages alone on bone health. Because of the existing literature regarding these beverages and bone health, a different study design may help to better observe those effects, such as a longitudinal study. From the results we found, I feel it wise to recommend to people to again, consume everything in moderation and be cognoscente of their dairy consumption, and further research may help us to draw more concrete conclusions.

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